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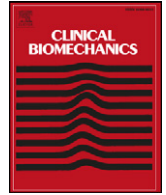
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Single level lumbar laminectomy alters segmental biomechanical behavior without affecting adjacent segments

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ABSTRACT

Background: Degenerative lumbar spinal stenosis causes neurological symptoms due to neural compression. Lumbar laminectomy is a commonly used treatment for symptomatic degenerative spinal stenosis. However, it is unknown if and to what extent single level laminectomy affects the range of motion and stiffness of treated and adjacent segments. An increase in range of motion and a decrease in stiffness are possible predictors of post-operative spondylolisthesis or spinal failure.

Methods: Twelve cadaveric human lumbar spines were obtained. After preloading, spines were tested in flexion-extension, lateral bending, and axial rotation. Subsequently, single level lumbar laminectomy analogous to clinical practice was performed at level lumbar 2 or 4. Thereafter, load–deformation tests were repeated. The range of motion and stiffness of treated and adjacent segments were calculated before and after laminectomy. Untreated segments were used as control group. Effects of laminectomy on stiffness and range of motion were tested, separately for treated, adjacent and control segments, using repeated measures analysis of variance.

Findings: Range of motion at the level of laminectomy increased significantly for flexion and extension (7.3%), lateral bending (7.5%), and axial rotation (12.2%). Range of motion of adjacent segments was only significantly affected in lateral bending (−7.7%). Stiffness was not affected by laminectomy.

Interpretation: The increase in range of motion of 7–12% does not seem to indicate the use of additional instrumentation to stabilize the lumbar spine. If instrumentation is still considered in a patient, its primary focus should be on re-stabilizing only the treated segment level.

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1. Introduction

In neurosurgical and orthopedic practice, elderly patients often present with symptomatic degenerative lumbar spinal stenosis (Verbiest, 1954). A commonly used surgical decompression procedure for this type of spinal stenosis is a single level facet-sparing laminectomy. Although the impinged nerves are decompressed and neurological symptoms, such as sciatica, claudication, and motor-, sensory- and reflex activities, improve following lumbar laminectomy (Weinstein et al., 2010), the anatomically destructive character of this technique obviously affects spinal biomechanics. In fact, laminectomy can lead to symptomatic postoperative lumbar clinical instability

i. e. spondylolisthesis or even postoperative failure of the spinal motion segment (Leone et al., 2007). Spondylolisthesis is the forward motion of a spinal segment with respect to its underlying segment. Spondylolysis or post-operative failure includes the fracturing of the posterior arch, facet joint and/or vertebral body. Both spondylolisthesis and spondylolysis generally occur post-operatively. Symptomatic clinical instability justifies re-operation to stabilize and fuse the unstable segment (Jansson et al., 2005). The incidence of iatrogenic spondylolisthesis after facet sparing laminectomy has been reported to range from 8 to 31% (Fox et al., 1996; Fu et al., 2008).

Previously it has been shown in vitro that facet-sparing laminectomy reduces the threshold at which shear forces and torsion moments cause lumbar spinal failure (Bisschop et al., 2012a, 2013c). It seems plausible that this type of decompressive surgery could also affect spinal biomechanics under submaximal loads. Reduced stiffness and increased range of motion under sub-maximal loading might make the segment more vulnerable and could lead to large tissue strains, impingements, or even tissue failure such as in iatrogenic spondylolisthesis and spondylolysis.

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Moreover, facet-sparing laminectomy could affect, due to its effects on the anatomical integrity of the lumbar spine, not only the treated segments but also adjacent segment levels. At present, little is known about the effects of single level facet-sparing lumbar laminectomy on the flexibility of the whole lumbar spine, i.e., on the range of motion (RoM) and stiffness in flexion–extension (FE), lateral bending (LB) and axial rotation (AR). Such effects are likely smaller than biomechanical changes caused by more extensive or multilevel decompressive surgery (Delank et al., 2010; Detwiler et al., 2003; Lee et al., 2010; Phillips et al., 2009; Quint et al., 1998).

In the present study, we quantified the effects of facet sparing single level laminectomy on the RoM and stiffness of lumbar (L) levels L2–L3, L3–L4 and L4–L5 in FE, LB and AR under sub-maximal loading, using twelve fresh frozen human cadaveric lumbar spines (L1–L5). We hypothesized that laminectomy causes an increase in the RoM and a reduction of stiffness of the treated segment while affecting adjacent segments of the lumbar spine to a lesser extent or not at all. An increase in RoM and a decrease of stiffness could, through a mechanism of cumulative damage, ultimately result in post-operative tissue failure, both in bone and soft tissue.

2. Methods

2.1. Specimens and specimen preparation

Twelve lumbar spines (L1–L5) were harvested from freshly frozen (-20°C) human cadavers (mean age 76.9 years, range 59–90 years). The bodies were donated to the Department of Anatomy of the UMC Utrecht by last will in accordance with the Dutch legislation and were destined for medical education and research. Body handling was done according to the guidelines of the Department of Anatomy. None of the deceased subjects had any history of spinal injury, spinal surgery or spinal metastatic disease. The spines were thawed before testing. Excessive soft tissue and muscle tissue was carefully removed, keeping the anterior and posterior longitudinal ligaments as well as the facet joints intact. During preparation, assessment and biomechanical testing, specimens were kept hydrated using 0.9% saline-soaked gauzes. Anteroposterior, lateral and oblique radiographs (Sedical® Digital Vet. DX-6, Arlington Heights, IL, USA) were made to determine whether bridging osteophytes were present in segments. Lumbar spines were considered eligible for this study in case no bridging osteophytes were seen. Magnetic resonance imaging (MRI, Siemens® Symphony 1.5 T: Syngo MR A30, software NUMARIS/4, Berlin, Germany), lateral and oblique radiographs and visual inspection also confirmed that facet joints were intact and no fractures of the pars interarticularis were present in segments before mechanical testing.

After imaging assessment, the top and bottom vertebrae of the lumbar spine (L1 and L5) were potted in a casting-mold and partially buried in a low melting point (48°C) bismuth alloy (Cerrolow-147; 48.0% bismuth, 25.6% lead, 12.0% tin, 9.6% Cadmium, and 4.0% indium) (Fig. 1a). The L1 and L5 vertebral bodies were firmly fixed into the alloy by adding screws into the vertebral body prior to submerging in the alloy. Disks of the top and bottom vertebra were placed parallel based on a visual inspection. Because the muscle tissue was thoroughly and carefully removed, the intervertebral disk and corresponding endplates were clearly visible. All articulating parts were kept free. Markers containing three LED's were rigidly fixed with screws to the anterior surface of the vertebral bodies of L2, L3 and L4 and to the casting-mold in which L5 was mounted (Fig. 2).

2.2. Biomechanical testing

The test setup was similar to previous studies (Bisschop et al., 2013b; Busscher et al., 2009, 2010; van Engelen et al., 2012). Segments were placed horizontally in a custom made four-point bending device in which FE, LB and AR were applied using a hydraulic materials testing

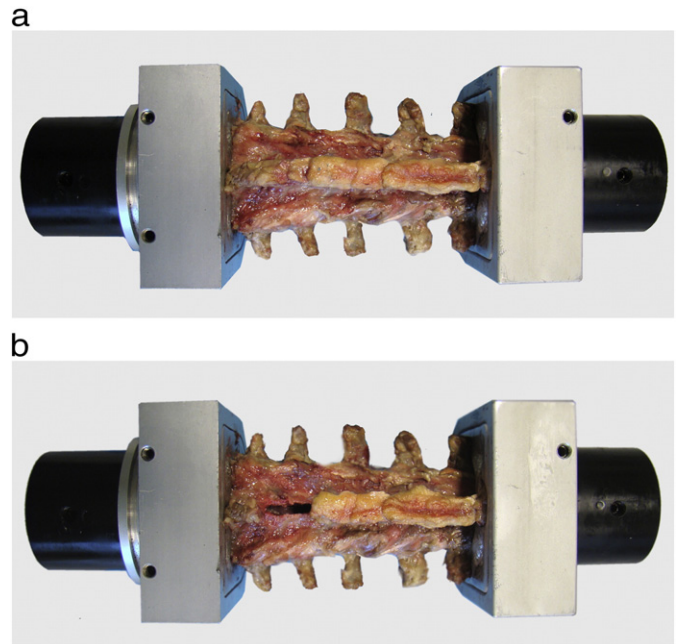


Fig. 1. a. Untreated spinal segment. Both L1 (shown right) and L5 (shown left) are potted in a casting-mold using a Bismuth-alloy. b. The same spinal segment as shown in panel a after performing a single level laminectomy on level L4. The spinous process, supraspinous and interspinous ligaments are removed while the facet-joint remained intact.

machine (Instron®, model 8872; Instron and IST, Norwood, Canada). This setup guarantees that forces generate a moment that is equal at all levels of the lumbar spine. During and in between testing procedures, spines were kept hydrated by covering them in saline-soaked gauzes.

Before testing, a compressive preload of 250 N was applied for 1 h. A pure axial compressive force was applied using a pneumatic cylinder. Calibration of axial compression was performed using a load cell (Hottinger Baldwin Messtechnik®, Force Transducer Type C2, Darmstadt, Germany). The chosen amount of axial preload, which is somewhat below the load of bodyweight and muscle forces in upright posture, was selected to allow for comparison with previous work (Bisschop et al., 2013b; Busscher et al., 2009, 2010; van Engelen et al., 2012) and to minimize the risk of buckling of the whole lumbar spine during preloading. During testing, no compressive load was applied, again, in order to prevent buckling of the multi-segmented spine (Patwardhan et al., 1999). Loads were applied up to a moment of 4 Nm at a constant angular velocity of 0.5° per second (Wilke et al., 1998). When a moment of $+4$ Nm was measured, the Instron reversed its loading direction until -4 Nm was reached. Each movement direction was tested for ten consecutive cycles (Bisschop et al., 2013b). Force and displacement of the Instron were recorded and digitized at 100 Hz (Instron® Fast Track 2, Norwood, Canada). All tests were performed at room temperature.

After the first set of measurements (FE, LB and AR), which took approximately 15–20 min, laminectomy was performed at level L2 of six randomly chosen lumbar spines and at level L4 of the remaining six lumbar spines. Laminectomy was performed by removing the spinous process and part of the lamina while leaving the facet joints intact (Fig. 1b). By using this technique, the integrity of supraspinous, interspinous and flavum ligaments is also lost. This technique is analogous to the standard clinical practice. Again, a compressive preload of 250 N was applied for 1 h. Thereafter spinal segments were tested in FE, LB and AR for another set of ten consecutive cycles. To correct for a possible systematic effect of test sequence the order of testing was varied over spines: the first six segments (three times laminectomy at level L2 and three times laminectomy at level L4) were tested in the order FE–LB–AR–laminectomy–AR–LB–FE while the remaining six segments

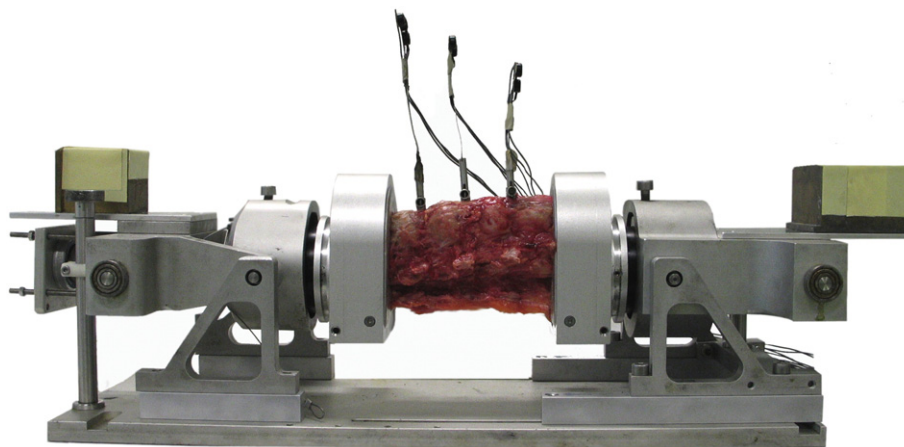


Fig. 2. Test setup for the application of continuous moments to the multilevel spinal segments. The specimen was rotated 90° for lateral bending. For axial rotation, the left side with the cup was rotated with a steel cable driven by the same mechanical testing system (not shown in this figure). The markers were rigidly fixed to the vertebrae. An Optotrak camera registered the movement of the LED's. The segment as shown was untreated. Markers on the casting-mold, containing L1 and L5 are not shown in this figure.

(three times laminectomy at level L2 and three times laminectomy at level L4) were tested in the order AR–FE–LB–laminectomy–LB–FE–AR.

During testing, motions of the LEDs on L2, L3, and L4 and the casting-mold containing L5 were recorded by an optoelectronic three-dimensional movement registration system with one array of three cameras (Optotrak® 3020, Northern Digital Inc., Waterloo, ON, Canada). Labview software was used for data acquisition. The sampling rate was 100 samples per second. The three-dimensional precision of this system at a distance of 2 m is about 0.01 mm. Before testing, the axes of the Optotrak system were aligned with the anatomic axes of the lumbar spine. Using the applied moment and Optotrak LED displacements a Matlab (Mathworks Inc., Natick, MA, USA) computer program calculated the load–displacement curves in the loaded direction for L3 relative to L2, for L4 relative to L3 and for L5 relative to L4. Subsequently, the biomechanical behavior (i.e. RoM and stiffness) of three segments was analyzed (L2–L3, L3–L4 and L4–L5).

2.3. Data analysis

Laminectomy was performed on a total of twelve segments (six times at level L2 and six times at level L4). The opposite untreated segments (six times segment L4–L5 and six times segment L2–L3, respectively) were used as control group. For each individual test (FE, LB and AR) the RoM (degrees) and stiffness (Nm/degree) before and after laminectomy per motion segment (L2–L3, L3–L4 and L4–L5) were calculated from the load–displacement data using Matlab (Mathworks®, Natick, MA, USA). The RoM was calculated from a double sigmoid curve fitted through the load–displacement data between an applied

load of -4 Nm and $+4$ Nm (Smit et al., 2011) (Fig. 3). The tenth cycle was used for analysis (Bisschop et al., 2013b). Stiffness was estimated by means of a least squares fit of a straight line through a section of the fitted curve between -1.0 Nm and $+1.0$ Nm with the slope of the line representing stiffness. For stiffness an average of ten cycles was used (Bisschop et al., 2013b). For both stiffness and RoM, upward-curves (i.e. from -4 Nm to $+4$ Nm) were used.

2.4. Statistical methods

Effects of laminectomy on stiffness and range of motion were tested, separately for treated, adjacent and control segments, using repeated measures analysis of variance. Pre-post treatment was used as within subjects factor. For treated and control segments, segment level (L2–L3 or L4–L5) was used as between subjects factor in the ANOVA. Adjacent segments were always levels L3–L4, but laminectomy had been either applied proximally (L2–L3) or distally (L4–L5). Therefore, for adjacent segments, treatment level rather than segment level was used as between subjects factor. A significance level of 5% was used. In case of significant interactions, Bonferroni-corrected paired t-tests were applied. The statistical analyses were performed using SPSS for Mac version 20.0 (SPSS Inc.®, Chicago, IL, USA).

3. Results

An overview of specimen characteristics is presented in Table 1. All statistical results are presented in Tables 2 and 3. RoM and stiffness in all motion directions of specimen 08 (L2–L3), specimen 09 (L2–L3)

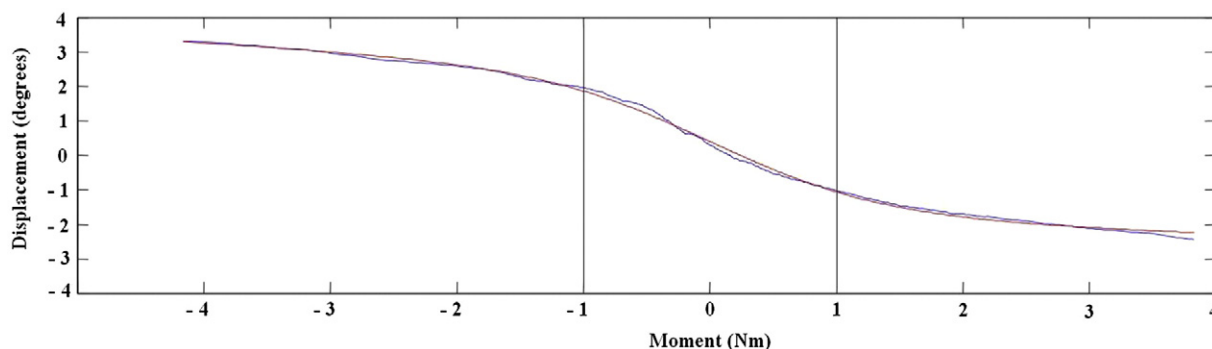


Fig. 3. Typical example of a load–displacement curve showing displacement (in degrees) on the x-axis and load (in Nm) on the y-axis. The blue line represents original data, while the pink line represents the fitted curve. At -1 Nm and 1 Nm two vertical lines are drawn to indicate that spinal stiffness is measured within this load-region.

and specimen 12 (L4–L5) were excluded from the analysis, due to severely irregular load–displacement curves. For RoM, 4 out of the remaining 198 analyzed cycles did not reach a fit of the double sigmoid curve of $r^2 > 0.95$ (range: 0.914–0.939). These cycles were individually assessed for quality; no cycles were excluded. For stiffness, 67 of the remaining 1980 measurements did not reach a linear fit of $r^2 > 0.95$ between -1.0 and 1.0 Nm, and were, after individual assessment, all excluded from the analysis due to severe irregularities in the data between -1.0 and 1.0 Nm.

Table 2 gives an overview of the effects of laminectomy on the RoM. After single level laminectomy, the RoM increased significantly for FE (7.3%; $P = 0.018$), LB (7.5%; $P = 0.007$), and AR (12.2%; $P = 0.021$) in treated segments. No significant effects of laminectomy were found for control segments. RoM in LB of the adjacent level L3–L4 decreased significantly (7.7%; $P = 0.033$) after laminectomy, while RoM of L3–L4 levels in FE and AR remained unaffected.

Effects of laminectomy on stiffness are presented in Table 3. Laminectomy did not significantly affect stiffness of the treated segments (six times L2–L3 and six times L4–L5) in all three motion directions. Also, no significant effects of laminectomy were found for the stiffness of control segments (six times L2–L3 and six times L4–L5) and of adjacent segments (twelve times L3–L4).

Finally, no significant effects for segment level and for the interaction between level and laminectomy were found for both RoM (Table 2) and stiffness (Table 3) in all motion directions.

4. Discussion

In the present study, we quantified the effects of facet-sparing single level laminectomy on the RoM and stiffness in FE, LB and AR under sub-maximal loading, using twelve fresh frozen human cadaveric lumbar spines. We found that laminectomy causes an increase in RoM of the treated segment while leaving stiffness unaffected. RoM and stiffness of adjacent segments also remained unaffected after laminectomy with exception of RoM in LB.

Other than previous studies, in which other types of uninstrumented and more extensive (multilevel) decompression surgery was performed in a similar test setup, this study also investigated the effect of decompression on adjacent segments (Delank et al., 2010; Detwiler et al., 2003; Lee et al., 2010; Phillips et al., 2009; Quint et al., 1998). Previous studies found, in contrast to our results, a substantially larger increase in RoM at treated segment levels. Quint et al. (1998) showed an increase in RoM of 32–35% during FE, 14% during LB and 117% during AR. However, these authors performed, besides a laminectomy, also a facetectomy and used a load-level of 7.5 Nm. Lee et al. (2010) also found substantially larger effects.

Although decompression techniques used by Lee et al. (2010) were similar to those in our study, differences in outcomes might have been caused by the application of higher loads (6–8 Nm) and axial compression (400 N) during testing. In the present study, a bending moment of 4 Nm was applied to the specimens in order to allow

comparison with previous work (Bisschop et al., 2013b; Busscher et al., 2009, 2010; van Engelen et al., 2012) and to anticipate on the fragility, and the subsequent risk of structural damage induced order effects of our relatively old and therefore possibly osteoporotic spines (Wilke et al., 1998). It was previously established that osteoporotic specimens might be damaged during testing when high loads (around 7–8 Nm) are applied (Wilke et al., 1998). We therefore restricted loading to 4 Nm, as even minimal damage to spinal structures might bias outcomes in subsequent testing procedures. Moreover, load deformation curves clearly leveled off at loads below 4 Nm (Fig. 3).

A possible explanation for the significant effects of laminectomy on RoM, while leaving stiffness unaffected is that we measured stiffness between -1 Nm and $+1$ Nm. In this deformation zone, which basically represents the neutral zone, the spinous process, part of the lamina, and posterior attached ligaments are most likely either not strained or strained only within the toe region of this stress–strain curve and therefore significant effects of laminectomy are not found. At 4 Nm there may have been some deformation of these structures, which likely increased after laminectomy.

In our study, we found RoM in FE around 6–7°, LB around 5–6° and AR around 3°. These RoMs are roughly 50% of the maximum range of motion that was found previously in vivo in healthy young adults (Mellor et al., 2009; Zhang et al., 2013).

The neutral zone was previously hypothesized as a clinically relevant measure for instability of the lumbar spine (Panjabi, 1992a, 1992b). Other studies determined the neutral zone as the zone in between the points of the largest changes in flexibility in the load–displacement curve (Smit et al., 2011). Unfortunately, these points could not reliably be detected in too many curves, as there were often small irregularities in load–displacement curves, possibly caused by degenerative deformities as a consequence of our aged sample. Consequently, we decided to measure stiffness between -1 Nm and $+1$ Nm in this study. As stated in the Introduction, a decrease in stiffness, as well as an increase in RoM, is from a biomechanical point-of-view the first sign of possible progression into an unstable situation and possibly increases the risk of progression into spondylolisthesis and/or spondylolysis.

Although spinal stiffness around the neutral zone remained unaffected after laminectomy, this type of decompression still results in a significantly increased RoM. Such an increase could lead to altered motion patterns and may therefore increase the risk of injury, including structural damage of the intervertebral disk and bony structures. However, when considering the magnitude of the effects on RoM in the present study, it seems plausible that these effects are not large enough to drastically increase the risk of clinical instability or failure at load levels investigated in the present study. Thus, the present findings do not seem to underline the urge for posterior instrumentation in order to (re-) stabilize the degenerative lumbar spine. However, previously we loaded single segments (L2–L3 and L4–L5) in axial rotation and shear loading under 1600 N compression (Bisschop et al., 2012a, 2013c). Since these studies considered single spinal levels, we were able to apply a relatively high axial compressive load during testing in order to mimic physiological conditions (Kingma et al., 2004, 2006). Effects of laminectomy on stiffness were larger than in the present study, 20% and 30–34% for rotation and shear, respectively. Possibly, determination of stiffness in higher load regions, combined with the axial compression, caused these differences. In addition, strength parameters in these studies were equally affected by laminectomy, a decrease of 18% after applying torsion moments and of a decrease of 44% in shear loading. These data suggest that considerations with regard to the question whether or not to apply posterior instrumentation at the treated and the adjacent level of the spine should possibly be based on failure risk (Bisschop et al., 2012b, 2013a) instead of on changes in RoM and stiffness around the neutral orientation. Note that we showed earlier that bone mineral density (BMD) is a strong predictor of the above-mentioned failure forces (Bisschop et al., 2012b, 2013a).

Table 1
Overview of specimens.

Donor	Gender	Age (years)	Level of laminectomy
Specimen 01	Female	83	L2
Specimen 02	Female	78	L2
Specimen 03	Male	59	L2
Specimen 04	Female	84	L2
Specimen 05	Male	71	L2
Specimen 06	Male	88	L2
Specimen 07	Female	90	L4
Specimen 08	Male	79	L4
Specimen 09	Male	70	L4
Specimen 10	Male	65	L4
Specimen 11	Male	73	L4
Specimen 12	Female	83	L4

Table 2
Statistical outcomes concerning spinal range of motion.

Range of motion	Segments	Untreated Degrees	After laminectomy Degrees	Untreated versus laminectomy		Segment level	Segment level × laminectomy
				%	P-values		
Flexion and extension	Laminectomy	6×: L2–L3 and 5×: L4–L5	Mean 6.30 (SD 2.44)	Mean 6.76 (SD 2.58)	± 7.26	0.018	0.322
	Adjacent	12×: L3–L4	Mean 6.35 (SD 2.55)	Mean 6.44 (SD 2.39)	+ 1.45	0.656	0.825
	Control	4×: L2–L3 and 6×: L4–L5	Mean 7.05 (SD 2.14)	Mean 7.00 (SD 2.17)	–0.73	0.967	0.236
Lateral bending	Laminectomy	6×: L2–L3 and 5×: L4–L5	Mean 4.82 (SD 1.62)	Mean 5.18 (SD 1.89)	± 7.50	0.007	0.413
	Adjacent	12×: L3–L4	Mean 5.73 (SD 2.42)	Mean 5.28 (SD 2.25)	–7.74	0.033	0.811
	Control	4×: L2–L3 and 6×: L4–L5	Mean 5.87 (SD 2.27)	Mean 5.81 (SD 2.23)	–1.03	0.674	0.861
Axial rotation	Laminectomy	6×: L2–L3 and 5×: L4–L5	Mean 2.79 (SD 1.90)	Mean 3.13 (SD 2.06)	± 12.19	0.021	0.616
	Adjacent	12×: L3–L4	Mean 2.83 (SD 1.62)	Mean 2.89 (SD 1.68)	+ 2.20	0.537	0.803
	Control	4×: L2–L3 and 6×: L4–L5	Mean 2.89 (SD 1.49)	Mean 2.90 (SD 1.37)	+ 0.29	0.839	0.315

The effect of laminectomy on the range of motion of spinal segments in flexion and extension, lateral bending and axial rotation. Effects of laminectomy on treated, adjacent and control segments were analyzed with repeated measures analysis of variance. SD is an abbreviation for standard deviation. Bold values indicate statistical significance at $P < 0.05$.

Only a limited number of studies investigated the effects of decompression surgery on adjacent levels. Cardoso et al. (2008) found that adjacent instability occurs after a more extensive decompressive surgery (i.e. facetectomy). Similar to our results, Delank et al. (2010) found that adjacent levels were not substantially affected after decompressive surgery, even after facetectomy. Nevertheless, we did find a significant effect of laminectomy on RoM in LB (-7.8% ; $P = 0.033$). Unfortunately, we are not able to explain these outcomes. A limitation of this study is that we combined both cranial (L3–L4 with respect to laminectomy on L4) and distal adjacent (L3–L4 with respect to laminectomy on L2) segments. The decision to analyze cranial and distal adjacent segments in a combined group was made on the basis of the limited number of specimen per group. We checked for effects of treated level in these segments and found no main effect or interaction. Therefore, we are confident that our results hold for both proximal and distal adjacent segments.

A possible confounder to this study is the effect of test sequence. For practical reasons, the order of testing was not completely randomized. While effects of test sequence cannot completely be excluded, we used more than one test sequence in order to limit bias. As we did not find any effects of repeated testing on our control segments, we can safely assume that sequence effects, if any, are small. Furthermore, we previously showed that repeated loading does have some small effects, but that these effects can be minimized by taking the tenth load cycle for RoM and by using an average over 10 cycles for stiffness (Bisschop et al., 2013b).

Another limitation is that we used a preload of 250 N for only 1 h. An axial preload can only partly simulate physiologic conditions, such as gravity and muscle forces. We did not apply axial loading during our test as application of compression combined with bending moments to a multi-segmented spine causes buckling (Patwardhan et al., 1999). Possibly, a short preload did not correspond with a daily loading

pattern. Due to losses of fluids in the disk in daily life, the effect of laminectomy might be enhanced. A repetitive movement was performed to mimic repetitive loading strains and for consideration of visco- and poro-elastic behavior (Bisschop et al., 2013b; Koeller et al., 1984; Zilch et al., 1980). Furthermore, during daily in vivo loading, the lumbar spine is often subjected to a combination of different loading directions. Combined loading of the lumbar spine was not investigated in this study.

Finally, we only studied a commonly used type of laminectomy with preservation of the facet-joints in this study. Since it might be argued that more extensive types of decompression such as facetectomy can enhance, and less extensive types of decompression such as laminotomy can diminish the effects found in the present study, it is important to study these effects in future studies in a similar test setup to be able to allow for comparison with this specific study. Unfortunately, we could only use elderly but otherwise ‘healthy’ spines with no signs of spinal stenosis, which is normally the indication for laminectomy. However, we doubt that results would be much different had we used stenotic spines. The reference data for the untreated segments might be different, but these would then not reflect the normal spine biomechanics, which may be preferable as a reference to the effects of surgery. The treated segments would likely show the same kinematics as reported here, since structures causing the stenosis are removed by the laminectomy. Nevertheless, a follow-up study with stenotic spines would be useful, although this may not be feasible considering the limited availability of human cadaveric material.

5. Conclusions

In conclusion, we studied the RoM and stiffness around the neutral orientation of twelve human lumbar spines per segment (L2–L3, L3–L4 and L4–L5) before and after single level facet-sparing laminectomy.

Table 3
Statistical outcomes concerning spinal stiffness.

Stiffness	Segments	Untreated Nm/degree	After laminectomy Nm/degree	Untreated versus laminectomy		Segment level	Segment level × laminectomy
				%	P-values		
Flexion and extension	Laminectomy	6×: L2–L3 and 5×: L4–L5	Mean 0.88 (SD 0.75)	Mean 0.81 (SD 0.68)	–8.34	0.126	0.740
	Adjacent	12×: L3–L4	Mean 0.78 (SD 0.60)	Mean 0.74 (SD 0.45)	–5.22	0.527	0.756
	Control	4×: L2–L3 and 6×: L4–L5	Mean 0.63 (SD 0.26)	Mean 0.58 (SD 0.28)	–6.65	0.354	0.239
Lateral bending	Laminectomy	6×: L2–L3 and 5×: L4–L5	Mean 1.28 (SD 1.08)	Mean 1.19 (SD 1.01)	–6.95	0.133	0.188
	Adjacent	12×: L3–L4	Mean 1.25 (SD 1.25)	Mean 1.11 (SD 1.10)	–11.75	0.327	0.311
	Control	4×: L2–L3 and 6×: L4–L5	Mean 1.03 (SD 0.94)	Mean 0.96 (SD 0.85)	–6.71	0.053	0.650
Axial rotation	Laminectomy	6×: L2–L3 and 5×: L4–L5	Mean 3.40 (SD 3.08)	Mean 3.33 (SD 3.01)	–1.98	0.880	0.288
	Adjacent	12×: L3–L4	Mean 3.18 (SD 3.33)	Mean 2.84 (SD 2.59)	–10.72	0.174	0.349
	Control	4×: L2–L3 and 6×: L4–L5	Mean 2.41 (SD 1.43)	Mean 2.05 (SD 0.94)	–14.96	0.058	0.558

The effect of laminectomy on the stiffness of spinal segments in flexion and extension, lateral bending and axial rotation. Effects of laminectomy on treated, adjacent and control segments were analyzed with repeated measures analysis of variance. SD is an abbreviation for standard deviation.

We found that laminectomy significantly affects segmental RoM in all three motion directions. However, the magnitude of the increase is limited, i.e., between 7% and 12%. RoM of adjacent segments was only affected in LB. Stiffness of both treated and adjacent segments was not affected. The present results do not suggest that additional instrumentation would be needed as standard procedure to stabilize the spine when performing single level laminectomy. However, when the use of spinal instrumentation is considered, its primary focus should be on restabilizing the level at which the laminectomy was performed.

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